Principles and approaches to abate seabird by-catch in longline fisheries

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Abstract

Mortality in longline fisheries is a critical global threat to most albatross and large petrel species. Here we identify key principles and approaches to identify and achieve broad use of effective seabird by-catch avoidance methods. Despite the availability of highly effective and cost-saving seabird avoidance methods, few longline fleets employ them. Given the political context and capacity of management authorities of the majority of longline fisheries, it is critical to identify seabird avoidance strategies that are not only highly effective, but are also economically viable and commercially practical. Adoption of an international performance standard for longline baited hook–sink rate, and prescribing minimum gear weighting designs that meet this standard that are achievable by all longline fisheries, would be an important step forward towards resolving low use of seabird avoidance methods by vessels, including those in illegal, unregulated and unreported fisheries. Due to differences between fleets, no single seabird avoidance measure is likely to be effective and practical in all longline fisheries. Therefore, testing of seabird avoidance methods in individual fleets is needed to determine efficacy and economic viability. Longline fishers should directly participate in these trials as they have a large repository of knowledge and skills to effectively develop and improve seabird by-catch avoidance techniques, and this provides industry with a sense of ownership for uptake of effective by-catch reduction methods. Establishing protected areas containing seabird colonies and adjacent waters within a nation's EEZ can be an expedient method to address seabird by-catch. However, establishing high seas marine protected areas to restrict longline fishing in seabird foraging areas, which would require extensive and dynamic boundaries and large buffer zones, may not be a viable short-term solution because of the extensive time anticipated to resolve legal complications with international treaties, to achieve international consensus and political will, and to acquire requisite extensive resources for surveillance and enforcement. Analysis of results of research on seabird avoidance methods reveals that the most reliable comparisons of the efficacy of alternative strategies are from comparing the effectiveness of methods tested in a single experiment. Benefits from standardizing the reporting of seabird by-catch rates to account for seabird abundance are described. To provide the most precise inputs for seabird population models, estimates of seabird mortality in longline fisheries should account for seabird falloff from hooks before hauling, delayed mortality of seabirds caught but freed from gear, and mortality caused by hooks discarded in offal.

Keywords albatross, by-catch, longline fisheries, seabird

A global problem

A critical global threat to albatrosses and large petrels is mortality in longline fisheries (Brothers *et al.* 1999a; Gilman 2001; Gilman and Freifeld 2003). Primarily while fishing gear is being set, seabirds are hooked or entangled, dragged underwater and drown as the gear sinks. The species of seabirds most frequently caught by longliners are albatrosses and petrels in the Southern Ocean; Arctic fulmar (*Fulmarus glacialis*) in North Atlantic fisheries; and albatrosses, gulls and fulmars in North Pacific fisheries (Brothers *et al.* 1999a). The health of populations of albatrosses and large petrels are most at risk.

While data on seabird by-catch from the world's longline fisheries are scarce, we do know that some seabird species are at risk of extinction, and that the incidental by-catch from longline fisheries contributes to their decline. According to International Union for the Conservation of Nature (IUCN) (The World Conservation Union), of the 61 species of seabirds affected by longline fisheries, 26 are threatened with extinction, including 17 species of albatrosses, and there is compelling evidence that longline mortality is a significant component in the declines of many of these species (Gales *et al.* 1998; Brothers *et al.* 1999a; IUCN 2003). For instance, large numbers of the wandering albatrosses (*Diomedea exulans*), a Southern Hemisphere species, are killed on longline hooks each year (Brothers 1991, 1995; Weimerskirch *et al.* 1997). The spectacled petrel (*Procellaria conspicillata*), another Southern Hemisphere species that is a single-island endemic with a small population, is taken in longline fisheries off the Atlantic coast of South America (Brothers *et al.* 1999a). The remaining albatrosses of the family Diomedeidae, the southern giant petrel (*Macronectes giganteus*), northern giant petrel (*M. halli*), white-chinned petrel (*Procellaria aequinoctialis*), and grey petrel (*P. cinerea*) of the Southern Ocean are other seabird species at risk of extinction that are killed in longline gear (Brothers *et al.* 1999a). Nineteen of the 21 species of albatross are now under global threat of extinction, with some species now numbering under 100 individuals.

Hundreds of thousands of seabirds, including tens of thousands of albatrosses, are caught annually in longline fisheries worldwide (Brothers 1991; Gilman 2001; CCAMLR 2002). Very few fishery observer programs are designed to record interactions with seabirds. As a result, quantitative information on seabird by-catch in longline fisheries is scarce and is available from only a small number of fisheries (Brothers *et al.* 1999a; Gilman 2001). Pirate fishing (illegal, unregulated and unreported) for Patagonian Toothfish (*Dissostichus eleginoides*) in the Southern Ocean, conducted primarily by vessels who choose a 'flag of convenience' from a State that neglects to ensure that vessels flying its flag comply with international fisheries management measures, may kill 145 000 seabirds per year (CCAMLR 2002). During the 1980s the Japanese pelagic longline tuna fleet south of 30° S latitude alone was estimated to take 44 000 albatrosses per year (Brothers 1991). Hawaii pelagic longline tuna and swordfish fisheries have caused an annual mortality of approximately 3000 albatrosses (US Fish and Wildlife Service 2004). However, recent changes in regulations designed to reduce seabird mortality and resulting from concerns over mortality of marine turtles may reduce seabird by-catch rates by over 90% and have reduced Hawaii longline swordfish fishing effort by about 50% of historical levels (US National Marine Fisheries Service 2002, 2004a). An estimated 2370–5610 albatrosses are taken annually in Peru's artisanal longline fleet (Jahncke *et al.* 2001). The Alaska demersal longline fisheries result in the annual mortality of roughly 15 430 seabirds of which 930 are albatrosses, based on observer data from 1993 to 2001, but an amendment to regulations to improve methods for minimizing seabird by-catch may reduce these mortality levels (US National Marine Fisheries Service 2004b).

Commercial longline fisheries range from small-scale traditional domestic artisanal fisheries, to small domestic commercial fleets, to modern mechanized industrialized fleets from distant water fishing nations, and is a fishing method used world-wide since the nineteenth century (Western Pacific Regional Fishery Management Council 1995; Brothers *et al.* 1999a). A longline consists of a main line with numerous baited hooks attached on branch lines.

Pelagic longlining, where gear is suspended from line drifting at the sea surface, mainly targets large tunas for sashimi markets, swordfish, billfishes and sharks, and is operated widely (Western Pacific Regional Fishery Management Council 1995; FAO 1998). Japan, Korea and Taiwan constitute the main high seas pelagic longline nations (FAO 1998; Brothers *et al.* 1999a). Distant-water vessels from China have recently entered the fishery and there has been rapid development of a longline fishery in Vietnam (Hampton and Williams 2003). The pelagic longline fisheries of temperate seas in the North Pacific and in the Southern Ocean result in high seabird by-catch (FAO 1998).

The largest demersal longline fisheries, where gear is set at the seabed, are in the North Atlantic and North Pacific. In the north-east Atlantic, Norwegian and Icelandic fleets comprise the majority of demersal longliners, and catch cod, haddock and tusk. In the north-west Atlantic, Canadian demersal longliners catch mainly cod. Demersal longliners of the north-east Pacific consist of domestic vessels from the US and Canada and catch mainly Pacific cod, halibut and sablefish (Brothers *et al.* 1999a). The main demersal longliners around Japan are small vessels operating in coastal areas. A longline fishery for Patagonian toothfish in the Southern Ocean has developed over the past few years with vessels from numerous countries (FAO 1998; IUCN 2000). The demersal longline fisheries of the north-east Pacific, North Atlantic, Southern Ocean and the Atlantic coast of South America result in high seabird by-catch (FAO 1998).

North Pacific

While many people think of albatrosses as birds of the Southern Ocean, there are four species that occur in the North Pacific, and unfortunately longline fisheries also affect these. North Pacific albatrosses include the short-tailed (*Phoebastria albatrus*), black-footed (*Phoebastria nigripes*), and Laysan (*P. immutabilis*). A fourth member of this genus, the waved albatross (*P. irrorata*) ranges north of the Equator, but does not forage as widely as the other three species (Anderson *et al.* 1998). The waved albatross' foraging distribution overlaps with the fishing grounds of the Peruvian artisanal pelagic longline fleet and Japanese eastern Pacific pelagic longline fleet off northern Peru, indicating that interactions with longline vessels is a potential threat to this species, which has been tentatively confirmed through a land-based survey of fishermen (Jahncke *et al.* 2001).

Pelagic longlining, where gear is suspended from line drifting at the sea surface, mainly targets large tunas for sashimi markets, swordfish and billfishes. Japan, China, Korea and Taiwan constitute the main high seas pelagic longline nations with fleets operating in the North Pacific (Brothers *et al.* 1999a). The US and Mexico have smaller pelagic longline fleets operating in the North Pacific. There are over 3000 pelagic longline vessels operating in the North Pacific. The US, Canada, Japan and Russia have demersal longline fisheries in the North Pacific, where gear is set at the seabed to target species such as halibut, cod and sablefish (Brothers *et al.* 1999a). There are approximately 17 000 demersal longline vessels operating in the North Pacific.

Some national governments have adopted regulations to manage seabird mortality in their North Pacific longline fisheries. The following countries have promulgated regulations requiring employment of specified seabird by-catch reduction methods and other measures: Japan (for both demersal and pelagic longline fleets); the US (for Alaska demersal and Hawaii and West coast pelagic longline fisheries); and Canada (for British Columbia demersal longline fisheries) (Government of Japan 2001; Canada Department of Fisheries and Oceans 2002; US National Marine Fisheries Service 2002, 2004a,b, 2004c). China, Korea, Mexico, Russia, and Taiwan do not have regulations to manage seabird interactions with longline gear (Brothers *et al.* 1999a; Huang and Day 2000; FAO 2003). Research on methods to minimize seabird by-catch in Hawaii's and Alaska's longline fisheries has been extensive and is the basis for regulations (US National Marine Fisheries Service 2002, 2004b; US Fish and Wildlife Service 2004).

The waved albatross is classified by IUCN as vulnerable because of its small breeding range. The short-tailed albatross is also classified by IUCN as vulnerable because of its small population and breeding range. Both species have increasing population trends (IUCN 2003). The Laysan albatross was listed as vulnerable for the first time by IUCN in 2003 based on a projected future decline of greater than 30% over three generations (84 years) (IUCN 2003). This was based on observations of a 30% decline in Laysan Albatross breeding pairs from 1992 to 2001, a 3.3% annual decline, at three monitored breeding colonies where 90% of the world's population nest (US Fish and Wildlife Service 2003). IUCN classifies the black-footed albatross as endangered on the basis of a projected future decline of more than 60% over the next three generations (56 years) (IUCN 2003), based on an observed 9.6% decline in black-footed albatross breeding pairs from 1992 to 2001, a 1.1% annual decline, based on monitoring data from three colonies in Hawaii where over 75% of the world population nests (US Fish and Wildlife Service 2003). The IUCN classifications for the black-footed and Laysan albatrosses are based on breeding pair counts over a 9-year period. Observations over this short time period may be within the margin of error or be a result of natural cyclical fluctuations. Seabirds, including the Laysan and black-footed albatrosses, demonstrate very large annual variability in breeding effort (Cousins and Cooper 2000; Hamer *et al.* 2002). It is difficult to derive confident population estimates and detect trends only from analysis of data from the monitoring of breeding pairs and over a short time period. Additional data and analyses are required to determine precise population trends and project population trends decades into the future.

Longline mortality effect on North Pacific albatross populations

While there is uncertainty in interpreting counts of breeding pairs, population modelling experiments on the black-footed albatross, using available estimates for total albatross mortality in North Pacific pelagic longline fisheries, raise concern that mortality in longline fisheries, if unabated, could threaten the existence of this species and poses a substantial threat to the other North Pacific albatross species (Cousins and Cooper 2000; Gilman 2001; Gilman and Freifeld 2003; Lewison and Crowder 2003; Niel and Lebreton 2005). Results from one population modelling experiment reported by Cousins and Cooper (2000) found that the world black-footed albatross population can withstand a loss of no more than 10 000 birds per year from all mortality sources and remain stable. A more recent expanded study revised this threshold to 17 700 (Niel and Lebreton 2005). Mortality in pelagic longline fisheries alone may exceed this threshold (Cousins *et al.* 2001; Gilman and Freifeld 2003; Lewison and Crowder 2003). Based on their lowest mortality estimates of 1.9% of the black-footed population killed per year in pelagic longline fisheries, Lewison and Crowder (2003) project that the black-footed albatross population likely will decline over the next 20 years if no measures are implemented to reduce their by-catch in longline fisheries.

Model results are driven by their inputs, and in this case, there is large uncertainty in the accuracy of several of the key inputs, including the estimate of total albatross mortality in North Pacific longline fisheries, as there are no seabird by-catch estimates available from onboard observer programs for the largest longline fleets operating in the North Pacific (Cousins *et al.* 2001; Gilman and Freifeld 2003) and because actual seabird mortality rates caused directly and indirectly by longline fisheries are higher than reported, as described in the following section. Despite the uncertainty in the model results, the results highlight the concern that mortality in longline fisheries could be causing declines in black-footed albatross population abundance (Lewison and Crowder 2003; Niel and Lebreton 2005). Similar modelling experiments have yet to be conducted for the other North Pacific albatrosses.

Loss of caught birds before haul

Seabird catch rates recorded on fishing vessels from observations of dead birds hauled aboard are underestimates as seabirds can fall from the hooks before hauling and there is unobserved discarding of incidentally caught seabirds by crew (Brothers 1991; Gales *et al.* 1998; Gilman *et al.* 2003a,b). In a study of Japanese longline tuna vessels fishing off Tasmania, Australia in 1988 an estimated 27% of seabirds caught during setting were not hauled aboard (Brothers 1991). Gales *et al.* (1998) studied seabird mortality in the Japanese longline southern bluefin tuna fishery within the Australian Fishing Zone from 1988 to 1995. As part of this study, observers dedicated to watching hauling to quantify seabird catch rates assessed the numbers of discards (seabirds hooked but not hauled aboard because of crew flicking or cutting them off the line while along side the vessel), which they would fail to observe during routine observations (when their primary task is to sample fish). Gales *et al.* (1998) found that the seabird catch rate in Tasmania was 95% higher on hauls with observations of seabirds cut off by crew than on routine observations. In a 2002 study in the Hawaii longline tuna fishery, Gilman *et al.* (2003a)) found that 34% of seabirds caught during setting were not hauled aboard. In a 2003 study in the Hawaii longline tuna and swordfish fisheries, Gilman *et al.* (2003b)) found that 28% of seabirds observed caught during setting were not hauled aboard. In the two Hawaii studies, crew did not attempt to dislodge or discard caught seabirds during hauling, and no live birds were caught on the lines as they were being hauled (Gilman *et al.* 2003a,b). Thus, the seabirds observed caught during the set, that were in fact caught, but were not hauled aboard can be inferred to have fallen from hooks because of fish predation, current, or other mechanical action during the line soak and haul.

Albatrosses have also been observed dying on their nests because of hook wounds. For instance, Weimerskirch and Jouventin (1987) observed wandering albatrosses injured from hooks likely discarded in offal from demersal longline fisheries. Longline vessels discarding hooks in offal and crew cutting free birds caught during hauling are two sources of these hooks (Brothers 1995). Mortality of one albatross of a breeding pair is expected to result in chick starvation and mortality, and the remaining adult albatross partner will take several years before mating again (Tasker and Becker 1992; Brothers 1995). Thus, actual seabird mortality rates caused directly and indirectly by longline fisheries are higher than reported. This highlights the need to adjust estimates of seabird mortality in longline fisheries to account for falloff of seabirds before the haul, delayed mortality for seabirds caught but freed from gear, and mortality caused by hooks discarded in offal to provide a more precise input for population models.

Lessons from results from research on seabird avoidance methods: case study from North Pacific pelagic longline fisheries

A review of research of methods designed to reduce seabird by-catch in North Pacific pelagic longline fisheries reveals that there are numerous methods that, when employed to prescription, can reduce seabird by-catch to negligible levels (Table 1).

Table 1 summarizes the results of research conducted on seabird avoidance methods in North Pacific pelagic longline fisheries. Analysis of this review of research results supports that the most reliable use of results from seabird by-catch research is a comparison of the effectiveness of the tested seabird avoidance methods employed in a single experiment. Otherwise, when comparing seabird by-catch rates for avoidance methods from two different experiments, the combined effect from numerous variables can result in significantly different seabird by-catch rates even for the same treatment used in different experiments. Even when normalized for seabird abundance, the results reported in Table 1 show a high degree of variability in treatment contact and capture rates from one year and one experiment to the next. For instance, the control treatment capture rate in the Hawaii longline swordfish fishery from McNamara *et al.* (1999) (2.23 captures per 1000 hooks per bird) is over 38 times higher than the control treatment capture rate observed by Boggs (2003). And the Boggs (2001) control treatment contact rate in the Hawaii longline swordfish fishery (7.60 contacts per

Table 1 Albatross interaction rates for seabird avoidance methods tested in North Pacific Ocean pelagic longline swordfish and tuna fisheries. Interaction rates are expressed normalized for seabird abundance (expressed as contacts or captures per 1000 hooks per bird) and without normalizing for bird abundance (expressed in parentheses as contacts or captures per 1000 hooks). Percent reductions are based on the normalized rates unless noted otherwise.

Study[1]	Treatment	Contact rate	Contact reduction (%)	Capture rate	Capture reduction (%)
McNamara *et al.* (1999)	Control[2]	32.8 (265.7)[3]		2.23 (18.0)	
Hawaii longline swordfish gear	Blue-dyed bait	7.6 (61.6)	77	0.12 (17.5)	95
	Towed buoy	16.1 (130.4)	51	0.26 (6.8)	88
	Offal discards	15.7 (124.7)	53	0.32 (2.3)	86
	Streamer line	15.7 (127.2)	52	0.47 (6.6)	79
	Night setting			(0.60)[4]	97[4]
Boggs (2001)	Control[2]	7.60 (313.5)[3,5]			
Hawaii longline swordfish gear	Blue-dyed bait	0.43 (20.5)[5]	94		
	Streamer line	1.82 (93.4)[5]	76		
	Additional 60 g weight at bait	0.61 (25.0)[5]	92		
Gilman *et al.* (2003a)	Control[2]	0.61 (75.93)		0.06 (4.24)	
Hawaii longline tuna gear	Underwater setting chute 9 m	0.03 (1.85)	95	0.00 (0.00)	100
Boggs (2003)	Control[2]	0.78 (27.1)		0.058 (2.0)	
Hawaii longline swordfish gear	Night setting	0.053 (4.8)	93	0.0013 (0.11)	98
	Night setting and blue-dyed bait	0.01 (0.98)	99	0.00 (0.00)	100
Gilman *et al.* (2003b),	Underwater setting chute 9 m	0.30 (5.0)		0.03 (0.6)	
Hawaii longline swordfish gear	Blue-dyed bait	2.37 (64.9)		0.08 (1.8)	
	Side-setting	0.08 (1.9)		0.01 (0.2)	
Gilman *et al.* (2003b),	Underwater setting chute 9 m	0.28 (10.3)	82[6]	0.05 (1.7)	38[6]
Hawaii longline tuna gear	Underwater setting chute 6.5 m	0.20 (5.6)	87[6]	0.01 (0.5)	88[6]
	Blue-dyed bait	0.61 (23.8)	60[6]	0.03 (1.2)	63[6]
	Side-setting	0.01 (0.1)	99[6]	0.00 (0.0)	100[6]

[1]Research has also been conducted by the Japan Fisheries Research Agency on the effectiveness of blue-dyed bait on reducing seabird interactions in Japan's longline tuna fishery in the western North Pacific Ocean (Minami and Kiyota 2002). Results were not published in a format that provides seabird interaction rates expressed as contact or capture per number of hooks or normalized rates for seabird abundance.

[2]Control treatments in McNamara *et al.* (1999); Boggs (2001), Gilman *et al.* (2003a) and Boggs (2003) entailed conventional fishing operations with no seabird avoidance methods.

[3]The different contact rates observed by Boggs (2001) and McNamara *et al.* (1999) may be explained by the use of different definitions of what constituted a seabird contact. McNamara *et al.* (1999) counted the total number of times a seabird came into contact with gear near the hook, even if the same bird contacted the gear multiple times, while Boggs (2001) defined a contact where only one contact per bait was recorded as a contact regardless of whether a single bird contacted a bait multiple times.

[4]This rate is not normalized for albatross abundance. McNamara *et al.* (1999) could not estimate seabird abundance during night setting. McNamara *et al.*'s (1999) control capture rate when not normalized for albatross abundance was 18.0 captures per 1000 hooks. Night setting reduced this control capture rate by 97%.

[5]Contact rates are averages of rates reported by Boggs (2001) for Laysan and black-footed albatrosses.

[6]Percent reductions use the control treatment contact and capture rates of Gilman *et al.* (2003a).

1000 hooks per bird) is over nine times higher than the control contact rate observed by Boggs (2003). This variability may be a result of several factors, including weather, season, bird behaviour, bird species complex, fishing practices (e.g. time of day when setting, use of deck lighting at night, offal discharge practices, type and condition of bait, amount and location of weights, length of branch lines, size of hooks, crew practices for deploying branch lines), location of fishing grounds, and consistency in observer's methods (Brothers 1991, 1995; Environment Australia 1998; Brothers *et al.* 1999a; Gilman 2001). Or in the case of the 9 m underwater setting chute, observed to have a contact rate over nine times higher in this study than in Gilman *et al.* (2003a), the variability in bird interaction rates is likely caused by engineering inconsistencies.

A seabird avoidance method or combination of methods that is appropriate for a fishery will consistently reduce seabird captures close to zero despite numerous sources of variability. Performance, measured as minimizing contact and capture rates, will not vary significantly when used on different vessels, in different years, with varying bird behaviour and species complex, with varying weather conditions, and other variables.

Fishery-specific solutions

Several seabird by-catch avoidance methods are capable of nearly eliminating bird captures in longline fisheries when effectively employed (Brothers 1995; Brothers *et al.* 1999a). Over the past 15 years, national governments, regional organizations and longline industries have developed and tested seabird avoidance methods in longline fisheries, which can be divided into six categories of methods (Brothers 1995; Brothers *et al.* 1999a; Gilman and Elliott 2002):

1 To alter fishing practices to avoid peak areas and periods of bird foraging (e.g. night setting, area and seasonal closures).

2 To reduce the detection of baited hooks by birds (e.g. blue-dyed bait, shielded lights).

3 To limit bird access to baited hooks (e.g. side-setting, underwater setting devices, thawed bait, addition of more weight closer to hooks, bait-casting machines).

4 To deter birds from taking baited hooks (e.g. bird-scaring line with streamers, acoustic deterrents, water cannon, towed buoy).

5 To reduce the attractiveness of baited hooks to birds (e.g. artificial lures, artificial smell).

6 To reduce injury to hooked birds (e.g. improved bird handling).

No single seabird avoidance measure can be expected to effectively and practicably reduce seabird mortality in all longline fisheries. Different seabird avoidance methods may be appropriate for different longline fisheries because of differences in the diving abilities of seabird species that interact with each fishery, vessel designs, fishing gear and fishing methods (Brothers *et al.* 1999a). There are many factors that influence the degree of seabird entanglements and hookings in an individual longline fishery and for a specific vessel. Fishing practices (e.g. automated vs. manual line hauling, method of gear deployment, season and time of day when setting, use of deck lighting at night, offal discharge practices, fishing grounds, condition of bait when setting, and proper use of mitigation measures), type and configuration of fishing gear (e.g. placement and amount of weight and concomitant baited hook sink rate, length of branch lines, size of hooks, use of light sticks, use of seabird avoidance methods), weather conditions when setting, and the complex of seabird species present influence the number of seabirds a specific vessel and fishery will catch (Brothers 1991, 1995; Bergin 1997; Environment Australia 1998; Brothers *et al.* 1999a; Cousins *et al.* 2001; Gilman 2001). Therefore, broad assessments in individual fisheries must precede advocacy for uptake of specific seabird avoidance methods.

For instance, while an underwater setting chute has been shown to be very effective at avoiding seabird interactions in the Hawaii pelagic longline tuna fleet (Gilman *et al.* 2003a), trials of the chute in the Australian pelagic longline fishery have not been as promising, likely because of the seabird species complex that interacts with the fishing vessels and their bait scavenging abilities and behavioural interactions, the weighting design of the fishing gear, and the use of live bait (Brothers *et al.* 2000). The deep-diving flesh-footed shearwater (*Puffinus carneipes*), one of the two most often caught species in Australian waters, can reach baits to a depth of 20 m, getting caught on baited hooks and bringing baited hooks to the surface to make them available to larger albatrosses, petrels and skua species, if these other species are present. Luckily deep-diving seabirds infrequently interact with the Hawaii longline fleet. In the Australian fishery, the chute may not be effective without being combined with additional mitigation measures and alterations to existing gear and fishing techniques in Australian waters where this seabird assemblage is seasonally present. For instance, when compared with the Hawaii longline tuna fishery, which uses 45–80 g swivels within 20–90 cm from the hook, the Australian longline tuna fleet, which places 20–38 g weights (if any) 3–4 fathoms from the hook, will have a slower hook sink rate than the Hawaii fishery, making baited hooks available to diving seabirds longer than if the weights were placed closer to the hooks. In addition, in the Australian fishery, the effect of using live bait on seabird capture is as yet unclear (the majority of the fleet uses a high proportion of live bait). The live bait is sufficiently small that it may be prone to swimming or flushing out of the chute prematurely at a shallow depth. And, the live bait, after being delivered at depth through the chute, may choose to swim towards the sea surface and increase its access to seabirds.

Industry direct involvement in research

Longline fishers are some of the most qualified people to develop and improve seabird by-catch mitigation techniques. Longline fishermen likely have a large repository of knowledge and information related to seabird by-catch, which can be tapped to contribute to finding effective and practical solutions. This has been demonstrated by successful collaborative research in US Alaska demersal longline fisheries (Melvin *et al.* 2001), US Hawaii pelagic longline fisheries (Fig. 1) (Gilman *et al.* 2003a,b) and various industry-lead voluntary fleet communication protocols to reduce by-catch by reporting real-time observations of by-catch hotspots (Gilman *et al.* 2005). Incentive instruments should be instituted to encourage longline fishers to participate in developing and testing new mitigation methods (Gilman *et al.* 2002). Mitigation methods that effectively avoid seabirds, do not reduce fishing efficiency, or better yet, increase fishing efficiency and provide operational benefits, have the highest chance of being accepted by industry. Fishermen and longline associations are encouraged to become active participants to address by-catch problems by participating in research and commercial demonstrations, implementing best practices, and supporting adoption of regulations based on best available science before restrictions, embargos and possible closures are imposed on them.

Most countries with longline fleets have a low degree of political will to address the problem of incidental seabird mortality, and have scarce resources for enforcement of seabird conservation measures. Few national fishery management authorities have frameworks to manage interactions between seabirds and longline vessels and do not require employment of effective seabird avoidance methods (Brothers *et al.* 1999a; BirdLife International 2003; FAO 2003). A bottom–up approach that fosters a sense of industry ownership for effective seabird mitigation methods, and concomitant voluntary compliance with legally required use of seabird avoidance methods, is needed in these countries. Longline fishers are among the most qualified people to innovate seabird mitigation methods, and should be encouraged to develop and test seabird avoidance methods. In this way, industry develops a sense of ownership for these tools and supports their required use.

Standardizing reporting seabird by-catch rates

Normalizing seabird interaction rates for bird abundance is an analysis approach consistent with the accepted understanding of animal abundance and the capture process (Ricker 1958; Seber 1973) derived from an early study on rats (Leslie and Davis 1939). Of all the factors that likely affect the level of bird interactions with longline gear per unit of effort, including weather conditions, seabird species complex, and differences in gear and fishing practices, seabird abundance may be one of the most important. Gilman *et al.* (2003a) demonstrated a highly significant linear correlation between albatross abundance and seabird interaction rates, confirming the hypothesis that seabird interaction rates should be normalized for seabird abundance. However, few studies report seabird by-catch rates normalized for seabird abundance (Table 1).

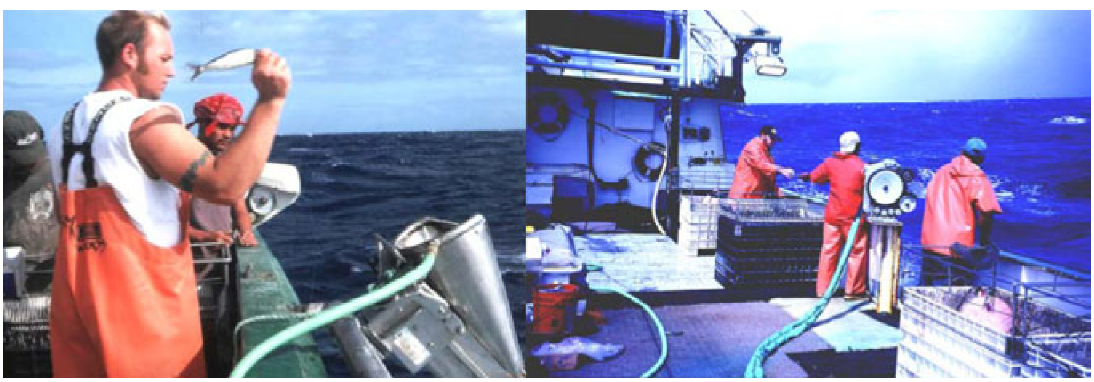

Figure 1 Industry led research on an underwater setting chute (left panel) and side setting (right panel) in the Hawaii pelagic longline fisheries.

To help explain the benefit of normalizing seabird interaction rates for bird abundance, consider the scenario where in one experiment an average of 15 albatrosses follow a vessel, and in another experiment 150 albatross follow a vessel, and both experiments are testing the same seabird avoidance method(s). Based on the results from Gilman *et al.* (2003a), we expect about 10 times more captures per unit effort (e.g. per 1000 hooks) in the second experiment than in the first, assuming all other potentially important factors (weather conditions, seabird species complex, different type of gear, different bait, etc.) that significantly effect bird capture rates are the same for the two experiments. If we did not normalize the capture rates from the two experiments by bird abundance, a comparison of the reported capture rates (presented as captures per 1000 hooks) would imply that the capture rate in the first experiment was 10 times lower than that of the second experiment. Therefore, normalizing capture and contact rates for bird abundance is important to allow for more accurate comparisons between seabird interaction rates reported from multiple experiments. It is also possible to test the influence of other variables besides bird abundance. For instance, Brothers *et al.* (1999b) and Cherel *et al.* (1996) have shown how environmental variables influence seabird by-catch rates.

Methods for observer program data collection on seabird by-catch

Adequate onboard observer coverage provides information on the level and trends in seabird mortality and allows fishery management authorities to determine if regulatory requirements and performance standards are being met.

Observer data collection protocols could be standardized to collect information on seabird abundance during setting and hauling. For instance, Gilman *et al.* (2003a,b) counted and recorded the number of each seabird species present within a 500 m × 500 m square area (within 250 m of port and starboard of the centre of the vessel stern and within 500 m behind the vessel) astern of the vessel every 15 min during the set. Observer programs could define a similar area around the vessel and frequency of counts to provide consistency in measurements of mean seabird abundance during sets and hauls. A smaller area around the vessel will need to be defined for seabird abundance observations during sets or hauls that occur at night.

Observers could record the number of seabird captures observed during the set and the number of seabirds hauled aboard, providing an estimate of the number of birds that fall off of hooks before hauling. And observers can record the number of seabirds caught during the haul. Gilman *et al.* (2003a) define a bird capture event during setting as when, '…a bird struggles persistently with outstretched, flapping wings and is finally lost to view astern as it maintains the same position of attachment to a hook'.

In addition, observers could record seabird capture by tote (also called snood bins or hook boxes), vs. recording seabird by-catch for an entire set, to maximize the sample size and reduce probable error of estimates of seabird by-catch rates.

Economic viability, practicality and enforceability

Given the political context and management frameworks of the majority of the worlds' longline fisheries, there is a need to focus on the commercial viability of by-catch reduction methods in order to catalyse changes in fishing methods and gear and regulatory measures that will abate longline by-catch. To resolve the global problem of seabird mortality in longline fisheries, there is a need to identify and institute the broad use of methods that not only have the capacity to minimize seabird capture, but which are also practical and convenient and provide crew with incentives to employ them consistently and effectively. It is critical to account for economic and social values of longline fisheries to achieve changes that abate by-catch (FAO 2004).

As the loss of bait to seabirds and concomitant reduction in catch of fish can be significant, the use of seabird avoidance measures is expected to be cost saving for longline fisheries. However, most longline fleets do not employ effective seabird avoidance methods despite the availability of effective methods that also increase fishing efficiency (Brothers *et al.* 1999a; Gilman 2001; FAO 2003). Reasons for this may be (i) low industry awareness of the availability, effectiveness and practicability of these seabird avoidance methods; (ii) few national fishery management authorities manage interactions between seabirds and longline vessels or require employment of effective seabird avoidance methods (Brothers *et al.* 1999a; BirdLife International 2003; FAO 2003; Gilman and Freifeld 2003); and (iii) lack of a sufficiently strong economic incentive for industry to change long-standing fishing practices. Recognizing this context of global longline fisheries, maximizing industry's sense of ownership for using effective seabird avoidance measures and providing industry with incentives for voluntary compliance are needed. The longline industry responds best to economic incentives and disincentives (Gilman *et al.* 2002). Seabird mitigation methods that increase fishing efficiency and have operational benefits have the best chance of being accepted by industry. Eco-labelling and certification programmes can also provide industry with strong market-based and social incentives to meet criteria to be certified as a sustainable fishery, including the employment of effective by-catch reduction methods, but requires adequate marketing of the label to make it economically viable for industry to participate (Gilman *et al.* 2002). Additionally, if regulations requiring the use of seabird avoidance methods are effectively enforced and carry sufficient economic consequences for non-compliance, broad industry compliance can be achieved.

Gilman *et al.* (2003a,b) provide an example of how research experiments can collect information to reveal each treatment's economic viability, practicality and enforceability. Analysing differences in alternative seabird avoidance methods' effect on bait retention, hook setting rates, and target fish catch-per-unit-effort; operational benefits and costs; time and money to adopt and employ; and enforceability is of high interest to industry, fishery management authorities and other stakeholders (Gilman *et al.* 2003a,b).

International initiatives and need for global performance standards to address IUU fishing

Several multilateral initiatives directly address seabird mortality in longline fisheries (Gilman 2001; Gilman and Freifeld 2003). These include the United Nations Food and Agriculture Organization's International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (FAO 1999); the Agreement on the Conservation of Albatrosses and Petrels (ACAP Interim Secretariat 2001); Resolutions and Recommendations adopted by IUCN (IUCN 1996, 2000; Gilman 2001); the United Nations Implementing Agreement (Haward *et al.* 1998); and the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Central and Western Pacific Region (Gilman 2001). A review of relevant multilateral accords, declarations, and actions by regional and international organizations reveals a need to augment international collaboration to adequately address seabird by-catch in longline fisheries, especially to address pirate longline fishing (Gilman 2001).

For example, establishing an international performance standard for longline hook sink rate, and prescribing gear weighting designs that meet this standard that are achievable by all longline fisheries, will contribute to resolving this problem of low vessel use of seabird avoidance methods. Line weighting is one effective seabird avoidance method that facilitates high compliance because gear manufacturers would build the gear according to the international convention, and crew would use gear as provided by gear suppliers. While standardized line weighting and hook sink rate alone would not adequately minimize seabird interactions in all fisheries, an international standard would be an important step forward, especially for fleets that currently do not employ any seabird by-catch reduction methods, including illegal, unregulated and unreported fisheries.

Marine protected areas, area and seasonal closures

Area and seasonal closures are management tools that can complement employment of other strategies to reduce by-catch. Closed areas can have substantial adverse economic effects on industry, but remain an available tool to fishery managers if alternative effective methods are not available. It may also be a more desirable option than a closed fishery.

Resource use restrictions of a marine protected area may displace effort to adjacent and potentially more sensitive and valuable areas, especially if an effective management regime does not exist for these other areas (Gilman 2002). And instituting a closure for one longline fleet may result in increased effort by another nation's longline fleet with fewer controls to manage by-catch. For instance, during a 4-year closure of the Hawaii longline swordfish fishery because of concerns over by-catch of sea turtles, swordfish supply to the US marketplace traditionally met by the Hawaii fleet was replaced by imports from foreign longline fleets, including from Mexico, Panama, Costa Rica and South Africa, which have substantially higher ratios of sea turtle captures to unit weight of swordfish catch and less stringent or no measures to manage seabird by-catch (Bartram and Kaneko 2004; Sarmiento 2004).

Establishing protected areas containing seabird nesting colonies and adjacent waters within a nation's Exclusive Economic Zone is potentially an expedient method to reduce interactions between seabirds and longline fisheries. For instance, to avoid interactions between the Hawaii-based longline fishery and the endangered Hawaiian monk seal (*Monachus schauinslandi*), the US Government prohibits longline fishing within 50 nautical mile around the north-western Hawaiian Islands, preventing seabird and longline interactions close to albatross colonies (US Department of the Interior and US Department of Commerce 2000). In addition, most of the north-western Hawaiian Islands have been part of the US National Wildlife Refuge System for the past century, where all commercial fishing activities are prohibited in nearshore waters, providing a small buffer for the more than 14 million nesting Pacific seabirds of 19 species, where 98% of the world's population of black-footed albatross and 99% of the world's population of Laysan albatross nest (US Fish and Wildlife Service 1999).

However, establishing high seas marine protected areas to restrict longline fishing in seabird foraging areas and migration routes, which would require extensive and dynamic boundaries defined in part by the location of large-scale oceanographic features and short-lived hydrographic features such as eddies and fronts, and would require extensive buffers (Hyrenbach *et al.* 2000), may not be a viable short-term solution (Thiel and Gilman 2001). This is in part the result of the extensive time anticipated to resolve legal complications with international treaties, to achieve international consensus and political will, and to acquire requisite extensive resources for surveillance and enforcement to implement high-seas marine protected areas (Thiel and Gilman 2001). Furthermore, design of a high seas protected area to address interactions between albatrosses and longline fisheries would need to account for albatrosses' complex foraging strategies, involving segregation by gender and age classes (Hyrenbach *et al.* 2000; Cousins *et al.* 2001).

International bodies have created marine protected areas on the high seas: The International Whaling Commission declared the Indian and Southern Oceans as no-take sanctuaries for whales, covering 30% of the world's oceans mostly on the high seas. Conventions governing international shipping have designated large areas of the ocean that include high seas as Special Areas where stringent restrictions apply regarding discharges from ships. Furthermore, under the United Nations Convention on the Law of the Sea, the International Seabed Authority could protect areas from minerals extraction beyond national jurisdiction where there is a risk of harm to the marine environment (Kelleher 1999). Recent developments within the framework of the United Nations Convention on the Law of the Sea and associated conventions may make it possible in the future to restrict fisheries activities on the high seas that are shown to undermine marine conservation (Kelleher 1999). However, it is unlikely that this treaty or the other 300 treaties involving the seas will be able to be used to establish areas closed to fishing on the high seas quickly enough to address the acute threat to several seabird species from interactions with longline gear.

Conclusions

Regional and national fishery management authorities, longline industries and other stakeholders need to mainstream the process of testing and adopting methods to reduce seabird by-catch in individual fleets. In fisheries where research has already begun, broadened experimentation is needed to refine, improve and confirm or deny their effectiveness and commercial viability. These broad trials can confirm expectations that the methods will perform consistently effective under variable conditions such as at different fishing grounds, and validate expectations that the methods will retain effectiveness over longer time periods. For instance, there are annual and decadal oscillations in oceanographic conditions (Lehodey *et al.* 1997) that could result in cyclical, temporal changes in seabird foraging behaviour and interactions with fishing gear. Such trials also have the benefit of developing industry familiarity with modified fishing gear and methods to develop support for fleet-wide use. The continued research can also test whether changes in fishing gear and methods change by-catch rates of other sensitive species. Research can be coordinated and designed to assess the effects of each treatment on the by-catch of all sensitive species.

As seabirds are highly migratory species, which frequently move in and between national jurisdictions and interact with longline vessels on the high seas, international collaboration is necessary to effectively address this problem. There are 11 countries that have jurisdiction over the islands where albatrosses breed (Argentina, Australia, Chile, Ecuador, France, Japan, Mexico, New Zealand, South Africa, UK and USA). Nine of these nations also operate longline fleets and provide access to longline fleets of other nations in waters where seabird by-catch occurs. Albatrosses and petrels also forage in international waters and waters of other countries (Brothers 1995). Several additional countries have major longline fisheries that result in the incidental by-catch of seabirds (Bulgaria, Canada, Iceland, Korea, Norway, Russia, Spain, Taiwan, and Ukraine). As a global and multinational problem, the solution to seabird mortality in longline fisheries will require international collaboration by management authorities, industry, and other stakeholders to share technical and financial resources to augment capacity and will to mitigate seabird and longline interactions.

Given the existence of relevant legally binding accords, the level of understanding of the source and extent of longline mortality, and the availability of both effective and cost-saving seabird avoidance methods, the potential exists to minimize seabird mortality in longline fisheries to insignificant levels. Similar mechanisms may not be available to address other significant threats to seabirds, such as contaminants, plastic ingestion and global climate change. To realize this potential, however, will require raising industry awareness of the operational benefits and economic incentives from using effective seabird avoidance methods, widely implementing relevant multilateral accords and initiatives, and establishing and enforcing effective seabird conservation measures. In addition, international attention to the issue appears to be waning in recent years. International attention needs to be reinvigorated and maintained until all problem longline fleets adopt effective seabird avoidance methods in order to exert pressure on longlining nations to address the problem, and provide capacity-building opportunities through disseminating lessons learnt.

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